MICROALLOYED STEEL EASY TO SEPARATE BY FRACTURE SPLITTING AT LOW TEMPERATURE AND FITTING MEMBER PRODUCED THROUGH SEPARATION BY FRACTURE SPLITTING AT LOW TEMPERATURE

FIELD OF THE INVENTION

The present invention relates to a microalloyed steel easy to separate by fracture splitting at low temperatures which is suitable for use as, e.g., a fitting member after forging and subsequent fracture splitting into two or more parts. The invention further relates to a fitting member obtained from the microalloyed steel through separation by fracture splitting at a low temperature, e.g., a connecting rod for engines.

BACKGROUND ART

Fitting members, such as, e.g., connecting rods for engines obtained by forging and subsequent separation into two parts to be connected to a crank shaft, have hitherto been produced by integral forging into a final shape, subsequent machining for finishing, and then cutting into two parts. However, not only this process necessitates an excess material as a cutting allowance for the part to be cut, but also the surfaces formed by the cutting should be finished by machining and polishing or the like. This process hence results in an increased cost.

For overcoming these problems, a process for producing, e.g., a connecting rod has been proposed which comprises processing a work to the final shape of the connecting rod and then separating the work by fracture splitting. In this fracture splitting method, notches 4 are formed in a larger end part 2 of a connecting rod 1 as shown in Fig. 1 (A) and a load is then applied thereto at room temperature to thereby separate the larger end part into a cap part 5 and a rod part 6 by fracture splitting as shown in Fig. 1 (B). In order for a material to be processed by this method, the material is required to have low ductility at room temperature so as to inhibit deformation during fracture splitting and to facilitate the splitting. Materials having regulated silicon, vanadium, and phosphorus contents so as to have reduced toughness/ductility at room temperature to satisfy that requirement (see "Steel Capable of Fracture Splitting at Room Temperature" in Fig. 2) have been developed (see, for example, JP-A-9-111412 and JP-A-10-219389).

However, when parts such as connecting rods are designed to be produced by processing such a steel, in which notch formation is the only procedure necessary for the easy separation of the work by fracture splitting without causing deformation, then influences of any minute defects present, e.g., notches, should generally be sufficiently taken into account, resulting in an increase in weight. There also is a problem that vanadium,

which is expensive, should be added in a large amount and this lessens the merit of reducing cost.

Under these circumstances, a method has been proposed in which a steel is separated by fracture splitting at a low temperature based not on an alloy composition but on the phenomenon in which steels embrittle at low temperatures (see, for example, JP A-2001-3924). By this method, a connecting rod which has sufficient toughness at use temperatures therefor can be produced from a steel which embrittles during fracture splitting only.

However, the fracture splitting of ordinary steel materials necessitates cooling to -130°C or lower (see Fig. 2) and it is necessary to use liquid nitrogen (-196°C) as a refrigerant for the cooling. There is hence a problem that the cost of cooling is exceedingly high.

SUMMARY OF THE INVENTION

An object of the invention is to provide a microalloyed steel which has moderate toughness in the range of use temperatures and can be easily separated by fracture splitting in a low-temperature region attainable at low cost, not to mention in the very-low-temperature region which is attainable by, e.g., cooling with liquid nitrogen and has been necessary for the existing materials to be separated by fracture splitting at a low temperature. Another object of the invention is to

provide a fitting member produced through separation by fracture splitting at a low temperature.

In order to eliminate the problems described above, the present inventors made intensive investigations, e.g., on toughness values required of machine parts to be used after separation by fracture splitting, such as connecting rods, on toughness values which enable fracture splitting to be easily conducted without causing deformation, and on the composition of a steel which satisfies these requirements concerning toughness value and can be easily separated by fracture splitting even with cooling with a refrigerant having a higher temperature than liquid nitrogen. As a result, the following have been found. In case where a material can be easily separated by fracture splitting at -60°C or lower without deforming, a low cost and ease of cooling are attained because a dry ice + ethanol freezing mixture can be used as a refrigerant. The temperature is preferably from -60 to -190°C, more preferably -60 to -80°C. In addition, the temperature is preferably -190°C when a liquid nitrogen is used. Moreover, the temperature is preferably -80°C when a dry ice + ethanol freezing mixture is used.

Toughness values required of machine parts to be used after separation by fracture splitting, such as connecting rods, are 10 J/cm^2 or higher in terms of Charpy impact strength (measured through a 2-mm V-notch test; the same applies hereinafter). Toughness values which enable easy separation

by fracture splitting without causing deformation are 5 J/cm^2 or lower in terms of Charpy impact strength. Furthermore, a steel which satisfies these requirements concerning toughness value and can be easily separated by fracture splitting at -60°C or lower without deforming has a composition regulated so as to have proper contents of carbon, silicon, phosphorus, manganese, chromium, copper, and nickel as specified in Claims.

The invention has been achieved based on these findings.

The invention provides a microalloyed steel easy to separate by fracture splitting at low temperatures, which comprises from 0.15 to 0.35 wt% carbon, from 0.5 to 2.0 wt% silicon, from 0.5 to 1.5 wt% manganese, from 0.03 to 0.15 wt% phosphorus, from 0.01 to 0.15 wt% sulfur, from 0.01 to 0.5 wt% copper, from 0.01 to 0.5 wt% nickel, from 0.01 to 1.0 wt% chromium, from 0.001 to 0.01 wt% soluble aluminium, from 0.005 to 0.035 wt% nitrogen, from 0.0001 to 0.01 wt% calcium, and from 0.001 to 0.01 wt% oxygen, and optionally contains one or more of up to 0.02 wt% titanium, up to 0.02 wt% zirconium, up to 0.3 wt% lead, and up to 0.3 wt% bismuth, the remainder comprising iron and inevitable impurities, and which satisfies the following relationships 1 and 2:

Relationship 1

$$0.6 \leq Ceq \leq 0.65$$

wherein $Ceq = C+0.07\times Si+0.16\times Mn+0.61\times P+0.19\times Cu+0.17\times Ni+0.2\times Cr$

Relationship 2

$0 \leq T_{Tr} \leq 1.5$

wherein $T_{Tr} = (C+0.8\times Si+5\times P)-0.5\times(Mn+Cr+Cu+Ni)$.

The invention further provides a fitting member produced through separation by fracture splitting at a low temperature from a microalloyed steel which comprises from 0.15 to 0.35 wt% carbon, from 0.5 to 2.0 wt% silicon, from 0.5 to 1.5 wt% manganese, from 0.03 to 0.15 wt% phosphorus, from 0.01 to 0.15 wt% sulfur, from 0.01 to 0.5 wt% copper, from 0.01 to 0.5 wt% nickel, from 0.01 to 1.0 wt% chromium, from 0.001 to 0.01 wt% soluble aluminium, from 0.005 to 0.035 wt% nitrogen, from 0.0001 to 0.01 wt% calcium, and from 0.001 to 0.01 wt% oxygen, and optionally contains one or more of up to 0.02 wt% titanium, up to 0.02 wt% zirconium, up to 0.3 wt% lead, and up to 0.3 wt% bismuth, the remainder comprising iron and inevitable impurities, and which satisfies the following relationships 1 and 2:

Relationship 1

$0.6 \leq Ceq \leq 0.85$

wherein $Ceq = C+0.07\times Si+0.16\times Mn+0.61\times P+0.19\times Cu+0.17\times Ni+0.2\times Cr$

Relationship 2

$0 \leq T_{Tr} \leq 1.5$

wherein $T_{Tr} = (C+0.8\times Si+5\times P)-0.5\times(Mn+Cr+Cu+Ni)$.

The microalloyed steel of the invention, which is ea y

to separate by fracture splitting at low temperatures and is suitable for use as, e.g., a connecting rod, and the fitting member of the invention, which is produced through separation by fracture splitting at a low temperature, each have the composition specified above. Because of this, the microalloyed steel and the fitting member in a use-temperature range have moderate toughness, i.e., a Charpy impact strength of 10 J/cm^2 or higher. At temperatures of -60°C and lower, the steel and the fitting member have such toughness that the steel can be easily separated by fracture splitting without deforming, i.e., a Charpy impact strength of 5 J/cm^2 or lower. In addition, since vanadium, which is an expensive additive element, is not used, the microalloyed steel and the fitting member can be produced at low cost.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is slant views for illustrating the shape of a connecting rod and a process for producing the same through separation by fracture splitting.

Fig. 2 is a graphic presentation showing the relationship between toughness and temperature in each of a steel of the invention, which is easy to separate by fracture splitting at low temperatures, a general steel, and the inventive steel disclosed in JP-A-9-111412.

Fig. 3 is a graphic presentation showing the relationship

between toughness and temperature in each of a steel having a low carbon content and a steel having a high carbon content.

In Figs., sign 11 is a hot-forged connecting rod, sign 2 is a larger end part, sign 3 is a smaller end part, sign 4 is a notch, sign 5 is a cap part, and sign 6 is a rod part.

DETAILED DESCRIPTION OF THE INVENTION

The reasons for the above-specified composition of the microalloyed steel of the invention, which can be easily separated by fracture splitting at low temperatures, and the fitting member of the invention, which is produced through separation by fracture splitting at a low temperature, and for the ranges of Ceq and T_{Tr} specified above will be explained next.

In the present invention, wt% has the same meaning as mass%.

Carbon: 0.15-0.35 wt%

Carbon is an element necessary for enhancing strength and obtaining an optimal impact transition curve. As shown in Fig. 3, steels having a low carbon content have a large difference between the upper shelf energy and the lower shelf energy and show an abrupt transition, although the transition temperatures thereof ar low. In contrast, steels having a

high carbon content have a small difference between the upper shelf energy and the lower shelf energy and show a gentle transition, although the transition temperatures thereof are higher. In the case where a steel is to be separated by fracture splitting at a temperature reduced to -60°C or lower as in the invention, the upper shelf energy thereof should be as high as possible and the impact strength thereof should decrease abruptly at temperatures of from -10 to -60°C to reach the level of lower shelf energy at -60°C and lower temperatures. For attaining this, the upper limit of carbon content in the steel of the invention is 0.35 wt%. On the other hand, the lower limit thereof is 0.15 wt% because too low carbon contents make it impossible to obtain sufficient strength.

Silicon: 0.5-2.0 wt%

Silicon is an element which not only functions to deoxidize during steel melting but also serves as a vanadium substitute to form a solid solution in ferrite and thereby improve the strength, yield strength, and fatigue strength of the ferrite, as a soft phase, which is a major cause of plastic deformation during fracture splitting. Namely, silicon inhibits deformation during fracture splitting and improves close contact between the surfaces formed by fracture splitting. Silicon is also an element which elevates the transition temperature to thereby improve suitability for separation by low-temperature

fracture splitting. For obtaining these effects, silicon should be contained in an amount of 0.5 wt% or larger. However, the upper limit of silicon content is 2 wt% because too high silicon contents result in considerably increased hardness and hence reduced machinability.

Manganese: 0.5-1.5 wt%

Manganese not only forms a solid solution in the base metal to enhance strength but also lowers the impact transition temperature to improve room-temperature toughness. Manganese is hence an element to be incorporated for these purposes. In the invention, manganese serves to inhibit the impact transition temperature from being excessively elevated by silicon and phosphorus. For obtaining these effects, manganese should be contained in an amount of 0.5 wt% or larger. However, the upper limit of manganese content is 1.5 wt% because too high manganese contents result in the formation of bainite through forging and this considerably increases hardness and reduces machinability.

Phosphorus: 0.03-0.15 wt%

Since phosphorus, which is an inevitable impurity, segregates at grain boundaries to reduce toughness, the content of phosphorus is generally reduced to the lowest possible level. However, in the invention, for which fracture splitting is

conducted, phosphorus is an element to be positively incorporated because it is highly effective in inhibiting deformation during fracture splitting and improving close contact between the surfaces formed by fracture splitting. Like silicon, phosphorus not only serves as a vanadium substitute to form a solid solution in ferrite to improve the strength of the ferrite and thereby effectively improve yield strength and fatigue strength, but also considerably elevates the impact transition temperature. Consequently, phosphorus is an element to be incorporated for these purposes also. For obtaining these effects, phosphorus should be contained in an amount of 0.03 wt% or larger. However, the upper limit of phosphorus content is 0.15 wt% because too high phosphorus contents result in a considerably reduced value of room-temperature impact strength. The content of phosphorus is preferably from 0.06 to 0.15 wt%.

Sulfur: 0.01-0.15 wt%

Sulfur forms a sulfide of manganese to improve machinability. It is hence an element to be incorporated for this purpose. For obtaining this effect, sulfur should be contained in an amount of 0.01 wt% or larger. However, the upper limit of sulfur content is 0.15 wt% because too high sulfur contents result in impaired suitability for hot processing.

Copper: 0.01-0.5 wt%, Nickel: 0.01-0.5 wt%

Copper and nickel improve room-temperature impact strength and lower the transition temperature like manganese and chromium. These are hence elements to be incorporated for these purposes. For obtaining these effects, copper and nickel each should be contained in an amount of 0.01 wt% or larger. However, the upper limit of copper content and nickel content is 0.5 wt% because too high contents thereof result in an increased cost (since copper and nickel are more expensive than manganese and chromium). In view of the fact that copper and nickel have come in an amount of from 0.05 to 0.2 wt% into materials obtained mainly from scraps through melting in an electric furnace, use of copper and nickel in amounts within that range is advantageous from the standpoint of cost.

Chromium: 0.01-1.0 wt%

Chromium not only forms a solid solution in the base metal to enhance strength but also lowers the impact transition temperature to heighten room-temperature toughness. Chromium is hence an element to be incorporated for these purposes. In the invention, chromium serves to inhibit the impact transition temperature from being excessively elevated by silicon and phosphorus. For obtaining these effects, chromium should be contained in an amount of 0.01 wt% or larger. However,

the upper limit of chromium content is 1.0 wt% because too high chromium contents result in the formation of bainite through forging and this considerably increases hardness and reduces machinability.

Soluble aluminium: 0.001-0.01 wt%

Soluble aluminium (acid-soluble aluminum) not only functions to deoxidize during steel melting, but also forms minute nitride particles to inhibit crystal grain enlargement during hot forging and improve strength. It is hence an element to be incorporated for these purposes. For obtaining these effects, soluble aluminium should be contained in an amount of 0.001 wt% or larger. However, the upper limit of soluble aluminium content is 0.01 wt% because even when the soluble aluminium content is increased excessively, the effects thereof are not heightened any more.

Nitrogen: 0.005-0.035 wt%

Nitrogen is an inevitable impurity. However, it is an element which combines with aluminum to form minute nitride particles dispersed in the steel and thereby inhibit crystal grain enlargement during hot forging. Although this effect is produced even when the nitrogen content is lower than 0.005 wt%, to diminish nitrogen to below 0.005 wt% is uneconomical. The lower limit of nitrogen content is hence 0.005 wt%. On

the other hand, the upper limit thereof is 0.035 wt% because too high nitrogen contents are causative of casting defects.

Calcium: 0.0001-0.01 wt%

Calcium displaces part of the manganese in MnS to form a solid solution of calcium in MnS, and this solid solution adheres to the cutting tools in machining and thereby improves machinability. It is hence an element to be incorporated for this purpose. For obtaining this effect, calcium should be contained in an amount of 0.0001 wt% or higher. However, the upper limit of calcium content is 0.01 wt% because even when calcium is added in too large an amount, the effect is not heightened any more.

Oxygen: 0.001-0.01 wt%

For obtaining the solid solution of calcium in MnS, it is necessary that the oxide of calcium should be present adjacently. Although oxygen is an inevitable impurity, it is an element necessary for the formation of the calcium oxide. For obtaining this effect, oxygen should be contained in an amount of 0.001 wt% or larger. However, the upper limit of oxygen content is 0.01 wt% because too high oxygen contents result in an increased amount of oxide inclusions and this is apt to cause cracks during hot processing.

Titanium: up to 0.02 wt%, Zirconium: up to 0.02 wt%

Titanium and zirconium serve to reduce the size of MnS particles dispersed and thereby improve chip friability in machining. These are hence elements to be incorporated for this purpose. However, the upper limit of titanium content and zirconium content is 0.02 wt% because too high contents thereof do not heighten the effect any more and are disadvantageous from the standpoint of profitability.

Lead: up to 0.3 wt%, Bithmuth: up to 0.3 wt%

Lead and bithmuth each improve machinability. These are hence elements to be incorporated according to need in the case where machinability is further improved. However, the upper limit of lead content and bithmuth content is 0.3 wt% because too high contents thereof reduce strength and suitability for hot processing.

$0.6 \leq Ceq \leq 0.85$

wherein Ceq =

$$C+0.07\times Si+0.16\times Mn+0.61\times P+0.19\times Cu+0.17\times Ni+0.2\times Cr.$$

Ceq is an index to the hardness of the microalloyed steel after forging. By regulating the value thereof, hardness after forging can be controlled. The reason for the regulation of Ceq to 0.6 or higher is that values thereof below 0.6 not only result in too low hardness and insufficient strength but

also lower the impact transition temperature, resulting in reduced suitability for separation by fracture splitting at -60°C or lower. The reason for the upper limit thereof of 0.85 is that too high values of Ceq result in reduced room-temperature toughness and too high hardness and hence in reduced machinability. The value of Ceq is preferably from 0.64 to 0.76.

$0 \leq T_{Tr} \leq 1.5$

wherein $T_{Tr} = (C+0.8\times Si+5\times P)-0.5\times(Mn+Cr+Cu+Ni)$.

As described above, impact transition temperature varies not only with hardness but also by the influence of alloying elements. Specifically, impact transition temperature increases with increasing carbon, silicon, and phosphorus contents, and decreases with increasing manganese, chromium, copper, and nickel contents. The reason why T_{Tr} is regulated to 0 or larger is that values of T_{Tr} below 0 result in a lowered impact transition temperature to reduce suitability for separation by fracture splitting at -60°C or lower. Namely, such low values of T_{Tr} do not result in a Charpy impact strength of 5 J/cm² or lower. The reason why the upper limit of T_{Tr} is 1.5 is that too high values of T_{Tr} result in too high an impact transition temperature and hence in reduced room-temperature toughness. Namely, such high values of T_{Tr} do not result in a Charpy impact strength of 10 J/cm² or higher.

The value of T_{Tr} is preferably from 0.3 to 1.4.

For the reasons given above, the microalloyed steel easy to separate by fracture splitting at low temperatures of the invention and the fitting member produced through separation by fracture splitting at a low temperature of the invention each have a composition within the range specified above and satisfy the two relationships.

EXAMPLES

Examples of the invention will be given below.

EXAMPLE 1

Steels according to the invention and comparative steels respectively having the compositions shown in Table 1 each were melted, formed into an ingot, and then hot forged into a material 50 mm square. These forged materials were heated at 1,200°C for 60 minutes and then hot-forged into cylindrical rods having a diameter of 22 mm. These rods were placed on a floor at an appropriate interval so as to avoid overlapping, and allowed to cool to room temperature. A hardness test piece, an Ono rotary bending fatigue test piece having a parallel-part diameter of 8 mm, and a JIS No.4 impact test piece were cut out of each cylindrical rod and subjected to tests.

Hardness was determined by measuring the hardness of

a 1/2 R part of each 22-mm cylindrical forged rod with a Rockwell hardness tester at room temperature. The results thereof are shown in Table 2.

In a fatigue test, the test piece was examined with an Ono rotary bending fatigue tester at room temperature. The results thereof are shown in Table 2.

In an impact test, the test piece was examined with a Charpy impact tester at room temperature and -60°C. The results thereof are shown in Table 2.

Table 1

	Kind of steel	Composition (wt%)												
		C	Si	Mn	P	S	Cu	Ni	Cr	s-Al	N	Ca	O	Others
Steel of the invention	1	0.25	1.50	1.21	0.100	0.102	0.10	0.05	0.15	0.0051	0.01	0.0013	0.0011	
	2	0.35	0.62	0.61	0.040	0.031	0.49	0.20	0.10	0.0092	0.005	0.0003	0.0030	
	3	0.15	2.00	1.50	0.150	0.140	0.10	0.48	0.15	0.0013	0.034	0.0098	0.0032	
	4	0.21	1.50	1.30	0.090	0.037	0.13	0.10	0.15	0.0100	0.007	0.0028	0.0011	Ti:0.009
	5	0.29	1.51	0.81	0.100	0.103	0.14	0.09	0.14	0.0060	0.008	0.0025	0.0012	Ti:0.008
	6	0.22	1.01	1.02	0.112	0.080	0.20	0.10	0.49	0.0034	0.011	0.0001	0.0061	Ti:0.007
	7	0.24	1.62	1.31	0.081	0.071	0.15	0.17	0.15	0.0061	0.012	0.0028	0.0052	Ti:0.018,Zr:0.002
	8	0.26	1.31	1.11	0.120	0.112	0.02	0.02	0.25	0.0029	0.01	0.0011	0.0022	Pb:0.15
	9	0.20	1.65	1.41	0.030	0.081	0.15	0.10	0.10	0.0015	0.011	0.0004	0.0029	Bi:0.05
	10	0.26	1.32	0.93	0.112	0.050	0.18	0.07	0.12	0.0031	0.015	0.0008	0.0039	Ti:0.008,Bi:0.04
Comparative steel	A	0.11	1.50	1.20	0.120	0.092	0.12	0.05	0.10	0.0032	0.02	0.0023	0.0022	
	B	0.43	1.50	1.20	0.110	0.101	0.10	0.05	0.20	0.0041	0.010	0.0014	0.0028	
	C	0.24	0.20	1.10	0.111	0.122	0.12	0.07	0.17	0.0029	0.009	0.0013	0.0032	
	D	0.32	2.50	1.20	0.120	0.101	0.20	0.15	0.20	0.0019	0.008	0.0021	0.0041	
	E	0.25	1.50	1.30	0.100	0.091	0.15	0.07	0.20	0.0021	0.011	0.0022	0.0031	
	F	0.25	1.53	1.21	0.010	0.098	0.21	0.16	0.21	0.0021	0.012	0.0021	0.0033	
	G	0.32	1.39	1.19	0.250	0.113	0.18	0.03	0.25	0.0019	0.009	0.0035	0.0029	
	H	0.25	1.62	1.31	0.101	0.198	0.21	0.12	0.21	0.0021	0.012	0.0012	0.0011	
	I	0.23	1.30	0.95	0.122	0.092	0.12	0.07	1.01	0.0019	0.012	0.0019	0.0033	
	J	0.25	1.70	1.01	0.101	0.102	0.17	0.08	0.21	0.0005	0.011	0.0015	0.0031	
	K	0.27	1.60	1.21	0.098	0.099	0.18	0.09	0.20	0.0021	0.001	0.0021	0.0018	
	L	0.34	1.8	0.8	0.148	0.091	0.05	0.06	0.12	0.0012	0.01	0.0021	0.0017	
	M	0.18	0.6	1.3	0.04	0.082	0.21	0.18	0.36	0.0018	0.011	0.0031	0.0011	
	N	0.45	0.25	0.8	0.02	0.1	0.15	0.15	0.2	0.02	0.008	-	0.0008	
	O	0.35	0.3	0.9	0.02	0.1	0.15	0.15	0.2	0.02	0.012	-	0.0009	V:0.1,Pb:0.18

Table 1 (continued)

	Kind of steel	Ceq	T_{Tr}
Steel of the invention	1	0.667	1.20
	2	0.663	0.35
	3	0.752	1.39
	4	0.650	1.02
	5	0.656	1.41
	6	0.675	0.68
	7	0.700	1.05
	8	0.660	1.21
	9	0.662	1.09
	10	0.648	1.20
Comparative steel	A	0.532	1.18
	B	0.862	1.41
	C	0.566	0.23
	D	0.884	2.05
	E	0.784	0.84
	F	0.666	0.63
	G	0.858	1.83
	H	0.737	1.13
	I	0.798	0.97
	J	0.680	1.38
	K	0.725	1.20
	L	0.728	2.01
	M	0.597	-0.17
	N	0.702	0.10
	O	0.621	-0.01

N indicates existing steel JIS S45C, while O indicates existing steel S35VC.

Table 2

	No.	Hardness (HRB)	Fatigue limit (MPa)	Impact strength (J/cm^2)		Remarks
				Room temp.	-60°C	
Steel of the invention	1	99.5	450	17	3	
	2	99.6	440	18	5	
	3	103.3	559	13	2	
	4	100.1	521	13	3	
	5	98.2	495	12	2	
	6	99.5	437	19	4	
	7	101.2	460	20	3	
	8	98.4	442	18	2	
	9	97.9	432	18	3	
	10	97.3	411	19	3	
Comparative steel	A	93.4	368	26	8	
	B	106.5	488	9	2	
	C	95.1	375	23	9	
	D	106.4	566	8	2	
	E	108.2	-	-	-	bainite generation
	F	98.7	387	25	12	
	G	105.0	573	9	2	
	H	100.9	378	13	3	
	I	107.9	-	-	-	bainite generation
	J	99.5	382	9	2	
	K	101.5	372	8	3	
	L	103.3	504	8	2	
	M	94.9	382	22	10	
	N	99.3	375	21	8	
	O	99.3	378	23	11	

N indicates existing steel JIS S45C, while O indicates existing steel S35VC.

The results given in Table 2 show the following. The steels according to the invention had a hardness of from 97.3 to 103.3 HRB, fatigue limit of from 411 to 559 MPa, and Charpy impact strengths (hereinafter referred to as "impact strengths") of from 13 to 20

J/cm^2 at room temperature and from 2 to 5 J/cm^2 at -60°C. Namely, each of these steels had a hardness around 100 HRB and a fatigue limit of 410 MPa or higher, and further had an impact strength at room temperature of 10 J/cm^2 or higher, which is required of connecting rods and the like, and an impact strength at -60°C of 5 J/cm^2 or lower, which is necessary for easy separation by fracture splitting without causing deformation.

In contrast, comparative steels A and C, which had a lower carbon or silicon content than in the inventive, had a lower hardness and lower fatigue limit than the steels according to the invention, although they have a higher room-temperature impact strength than the steels according to the invention. Furthermore, the impact strengths thereof at -60°C were 8 J/cm^2 and 9 J/cm^2, respectively, which are higher than the upper limit of impact strength necessary for easy separation by fracture splitting without causing deformation (5 J/cm^2).

Comparative steel B, which had a higher carbon content and a higher value of Ceq than in the invention, was almost equal in hardness and fatigue limit to the steels according to the invention and the impact strength thereof at -60°C was not higher than the upper limit of impact strength necessary for easy separation by fracture splitting without causing deformation. However, the impact strength thereof at room temperature was 9 J/cm^2, which was lower than the lower limit of impact strength required of connecting rods or the like (10 J/cm^2).

Comparative steels D and G, which had a higher silicon or phosphorus content and higher values of Ceq and T_{Tr} than in the invention, had a higher hardness and a higher fatigue limit than the steels according to the invention. The impact strengths thereof at -60°C were not higher than the upper limit of impact strength necessary for easy separation by fracture splitting without causing deformation. However, the impact strengths thereof at room temperature were 8 J/cm^2 and 9 J/cm^2, respectively, which are lower than the lower limit of impact strength required of connecting rods or the like.

Comparative steels E and I, which had a higher manganese or chromium content than in the invention, had a higher hardness than the steels according to the invention and considerably reduced machinability due to the high hardness because they had a bainite structure. Since it was apparent that these steels were unsuitable for use as machine parts such as connecting rods, they were not examined for fatigue limit and impact strength.

Comparative steel F, which had a lower phosphorus content than in the invention, was almost equal in hardness to the steels according to the invention and had a higher room-temperature impact strength than the steels according to the invention. However, it had a lower fatigue limit than the steels according to the invention. Furthermore, the impact strength thereof at -60°C was 12 J/cm^2, which is higher than the upper limit of impact strength necessary for easy separation by fracture splitting without causing

deformation.

Comparative steel H, which had a higher sulfur content than in the invention, was almost equal in hardness to the steels according to the invention and had a room-temperature impact strength not lower than the lower limit of impact strength required of connecting rods or the like. It further had a -60°C impact strength not higher than the upper limit of impact strength necessary for easy separation by fracture splitting without causing deformation. However, this steel had a lower fatigue limit than the steels according to the invention.

Comparative steels J and K, which had a lower soluble aluminium or nitrogen content than in the invention, were almost equal in hardness to the steels according to the invention and had a -60°C impact strength not higher than the upper limit of impact strength necessary for easy separation by fracture splitting without causing deformation. However, they had a lower fatigue limit than the steels according to the invention, and the impact strengths thereof at room temperature were 9 J/cm^2 and 8 J/cm^2, respectively, which are lower than the lower limit of impact strength required of connecting rods or the like.

Comparative steel L, which had a higher value of T_{rr} than in the invention, was almost equal in hardness and fatigue limit to the steels according to the invention and had a -60°C impact strength not higher than the upper limit of impact strength necessary for easy separation by fracture splitting without causing

deformation. However, the impact strength thereof at room temperature was 8 J/cm^2, which is lower than the lower limit of impact strength required of connecting rods or the like.

Comparative steel M, which had a lower value of T_{Tr} than in the invention, had a room-temperature impact strength not lower than the lower limit of impact strength required of connecting rods or the like. However, it had a lower hardness and lower fatigue limit than the steels according to the invention. Furthermore, the impact strength thereof at -60°C was 10 J/cm^2, which is higher than the upper limit of impact strength necessary for easy separation by fracture splitting without causing deformation.

Comparative steel N, which was an existing steel (JIS S45C) having a high carbon content, having a lower oxygen content than the steels according to the invention, and containing no calcium, had a room-temperature impact strength not lower than the lower limit of impact strength required of connecting rods or the like and was almost equal in hardness to the steels according to the invention. However, this steel had a lower fatigue limit than the steels according to the invention, and the impact strength thereof at 60°C was 8 J/cm^2, which is higher than the upper limit of impact strength necessary for easy separation by fracture splitting without causing deformation.

Comparative steel O, which was an existing steel (S35VC) having a lower value of T_{Tr} than in the invention and containing vanadium and no calcium, had a room-temperature impact strength

not lower than the lower limit of impact strength required of connecting rods or the like and was almost equal in hardness to the steels according to the invention. However, this steel had a lower fatigue limit than the steels according to the invention, and the impact strength thereof at -60°C was 11 J/cm^2, which is higher than the upper limit of impact strength necessary for easy separation by fracture splitting without causing deformation.

EXAMPLE 2

Microalloyed steel 1 according to the invention and comparative microalloyed steel O were hot-forged into a connecting rod shape and then finished by machining. In each finished shape, a notch having a depth of 0.5 mm, tip-part R of 0.2 mm, and notch angle of 60° was formed in each of the positions at which the larger end part was to be separated by fracture splitting. Separation by fracture splitting was conducted at each of a liquid-nitrogen temperature, -60°C, and room temperature. Changes in roundness through the separation were measured. The results obtained are shown in Table 3.

Table 3

	No.	Microalloyed steel used	Fracture splitting temperature		
			Liquid-nitrogen temperature	-60°C	Room temperature
Connecting rod of the invention	11	Steel 1 according to the invention	10 µm	12 µm	120 µm
Comparative connecting rod	P	Comparative steel O	40 µm	100 µm	not split

Connecting rod 11 according to the invention underwent an exceedingly slight change in roundness through separation by -60°C fracture splitting, not to mention through separation by fracture splitting at the liquid-nitrogen temperature. At room temperature, separation was not easy with the notches imparted because of the improved toughness, resulting in a large change in roundness. In contrast, comparative connecting rod P had a large change in roundness through separation by fracture splitting even with cooling to liquid-nitrogen temperature.

Due to the constitutions described above, the microalloyed steel easy to separate by fracture splitting at low temperatures of the invention and the fitting member produced through separation by fracture splitting at a low temperature of the invention produce the following excellent effects.

(1) In an ordinary use-temperature range, the steel has a toughness value not lower than the lower limit of toughness required of machine parts such as connecting rods (10 J/cm^2 in terms of Charpy impact strength). At temperatures of -60°C and lower to be used for cooling

for separation by fracture splitting, the steel has a toughness value not higher than the upper limit of toughness necessary for easy separation by fracture splitting without causing deformation (5 J/cm^2 in terms of Charpy impact strength).

(2) The steel can be easily separated by fracture splitting at a temperature of -60°C or below which is higher than the temperatures used for steels proposed so far.

(3) The steel and the fitting member are inexpensive because they contain no expensive elements.

While the invention has been described in detail and with reference to specific embodiments thereof, it will be apparent to one skilled in the art that various changes and modifications can be made therein without departing from the scope thereof.

This application is based on Japanese patent applications No. 2002-336047 filed on November 20, 2002 and No. 2003-356201 filed on October 16, 2003, the entire contents thereof being hereby incorporated by reference.